functional indices—systolic and diastolic ventricular volumes, cardiac output, and ejection fraction.

Computed tomographic angiocardiography provides valuable anatomic information in three dimensions regarding the size and structure of cardiac chambers, the caliber of pulmonary arteries and aorta, septal defects, the connection between ventricles and great vessels, the compression of airways by vascular structures, and position and patency of shunts and stents. In most cases, the image information is analogous or even superior to that provided by conventional projectional angiocardiography. Computed tomography uses less contrast material and radiation dose than angiography, which often requires administering multiple doses and biplane filming in various projections.

Although cardiac catheterization is still required for percutaneous interventions—balloon dilatation, stent placement, and embolization—and it is the only test to measure intracardiac and intravascular pressure curves and oxygen saturation, electron-beam CT can also provide detailed functional information, as mentioned earlier.

Emerging indications for cardiac CT are as follows: possible aortic coarctation; preoperative evaluation of pulmonary vascularity in patients with cyanotic heart disease who are being considered for palliative shunt placement; unifocalization of aortopulmonary collaterals or complete repair; assessment of complex postoperative anatomy; and the visualization of airway compression by vascular rings, slings, dilated vessels, and shunts. If cardiac catheterization is still required to further assess cardiac function and to guide endovascular intervention, the performance of cardiac CT on the day before catheterization substantially reduces the number of administrations and projections, the amount of contrast material required, and the procedure time, which should lead to savings in radiation dose and costs. Close cooperation between radiologists and pediatric cardiologists is required, especially in the user-interactive three-dimensional rendering and interpretation of the CT data. Noninvasive high-resolution "four-dimensional" cardiac imaging with CT has now become a reality, and its more general application in multidisciplinary cardiovascular research and treatment centers should have an important influence on patient management and outcome.

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Doppler Ultrasonography of Transjugular Intrahepatic Portosystemic Shunts

THE TRANSJUGULAR INTRAHEPATIC portosystemic shunt (TIPS) procedure is a nonoperative treatment option for managing variceal hemorrhage from portal hypertension. In this percutaneous procedure, an expandable metallic stent is placed in the liver to create a channel between a hepatic vein and a portal vein. Its creation has been shown to be feasible and effective, and it has become an accepted method for treating patients with portal hypertension and acute variceal bleeding. These shunts can become stenotic or occluded, however. Because the likelihood of shunt complications increases with length of time since insertion and the risk of recurrent variceal bleeding is directly related to shunt patency, a noninvasive, widely available, and relatively inexpensive means for assessing shunt function is of great importance.

Sonography is a valuable diagnostic tool in the noninvasive evaluation of hepatic parenchymal disease and hepatic vasculature. With the use of Doppler sonography, functional hemodynamic information regarding vascular patency, flow direction, and flow patterns can be obtained. Doppler sonography has been used to evaluate conventional, surgically created portosystemic shunts, and recent reports have shown this technique to be of value in demonstrating changes in hepatic hemodynamics after TIPS placement. The intrahepatic location of the TIPS makes it amenable to sonographic assessment. On gray-scale sonographic imaging, the walls of the stent are seen as highly echogenic parallel lines. Sonographic protocol includes spectral and color Doppler insonation of the main and intraparenchymal right and left portal veins, the TIPS stent, and the hepatic veins. The shunt is imaged along its long axis, and the maximum flow velocity within the TIPS is measured. The peak flow velocity by Doppler ultrasonography within a patent TIPS ranges from 50 to 270 cm per second.

Doppler sonography demonstrates TIPS flow and detects thrombosis. The absence of detectable flow within a TIPS indicates shunt thrombosis. Several Doppler sonographic variables have been studied in an effort to investigate which changes are most indicative of shunt dysfunction and, in particular, of TIPS stenosis. The variables that have been used include portal vein flow velocity and portal blood flow, maximum flow velocity within the shunt, the direction of flow within the intrahepatic portal venous branches, temporal change in peak stent velocity, and the direction of flow in the draining hepatic vein.

Reduced maximum flow velocities within a TIPS, measured in the intrahepatic portion of the stent, suggest stenoses that most often occur downstream, at the hepatic venous end of the shunt, or in the draining hepatic vein. Doppler measurement of a maximum flow velocity within the TIPS of 50 cm per second or less is a useful and suggestive indication of shunt stenosis.

Routinely doing baseline postprocedure and follow-up Doppler sonographic studies in patients with TIPS aids in screening for shunt complications and in selecting patients who will benefit from therapeutic intervention, including revising stenotic shunts. Although long-term complications are known to occur, TIPS function can be

maintained in most patients by careful surveillance and periodic percutaneous angiographic intervention when indicated. The long-term clinical effect of routine screening by Doppler ultrasonography is not yet known, but the early detection and prompt revision of occluded or tightly stenotic shunts will likely decrease the frequency of recurrent variceal bleeding.

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Spiral Computed Tomography and Magnetic Resonance Imaging in the Detection of Pulmonary Emboli

PULMONARY EMBOLISM following lower extremity deep venous thrombosis is the third most common cardiovascular disease. The initial assessment of pulmonary embolism begins with a high index of suspicion. This is difficult because pulmonary emboli often present with nonspecific chest radiographs and normal arterial gas measurements and electrocardiograms. The current imaging workup of pulmonary embolism includes varying combinations of peripheral venous ultrasonography, ventilation-perfusion scanning, and pulmonary angiography.

Ventilation-perfusion scanning is perhaps the best known tool to aid in the diagnosis of pulmonary embolism. This is only an indirect test for pulmonary embolism that uses multiple scintigraphic criteria to arrive at a probability or likelihood for pulmonary embolism, rather than direct visualization. A normal scan virtually excludes the diagnosis whereas a low-probability scan, combined with a low pretest probability, lowers the likelihood of pulmonary embolus enough to preclude the use of angiography or anticoagulation in most patients. When a high-probability scan is coupled with a high pretest probability, the likelihood of pulmonary embolism being present exceeds 95%.

Unfortunately, most patients do not fall into these diagnostic categories, where pulmonary embolus can be reliably confirmed or excluded. (This remains true despite the recent revision of the Prospective Investigation of Pulmonary Embolism Diagnosis [PIOPED] criterion that broadens the definition of a low-probability scan.) This unreliability of ventilation-perfusion scanning in most clinical situations, combined with the perceived cost and morbidity of pulmonary angiography, has helped spur the recent interest in the development and application of new imaging techniques.

Spiral computed tomography (CT), which is becoming widely available, can now directly visualize pulmonary emboli noninvasively. Conventional CT requires relatively long scan times that, combined with respiratory motion, create artifacts that severely limit its usefulness as a screening tool for pulmonary embolism. Spiral or helical CT acquires images as a volume (cylinder) of data rather than a slice at a time as with conventional CT scanning. This volume can be acquired in a single breath, thereby diminishing motion artifact. The images are viewed as slices taken from this volume, and if these slices are overlapped, other types of artifact (volume averaging) are diminished.

Spiral CT for pulmonary emboli is done with the administration of 100 to 150 ml of a contrast medium intravenously through a power injector. It is given at 3 to 4 ml per second, which requires good peripheral venous access. During the contrast infusion, the scanner acquires one or two volumes of data, which requires either a 12- to 15-second or a 24- to 30-second breath hold, respectively. Timing of the contrast bolus with respect to the scanning is crucial. To select the best timing for the study, a small bolus of contrast medium may be administered, with preliminary scanning done through the main pulmonary arteries. This step can be particularly helpful in patients with pulmonary hypertension and other cardiac diseases who might have abnormal circulation times.

In many recent comparisons with angiography, spiral CT done in this manner has shown specificity and sensitivity of 90% or more for main, lobar, and segmental pulmonary emboli. The diagnosis of segmental pulmonary emboli, however, requires optimal technique and may necessitate slicing the imaged volume in planes along the axes of pulmonary vessels that run obliquely through the lung. An excellent knowledge of hilar and pulmonary vascular anatomy is also important so that false-positive and false-negative diagnoses are avoided. Hilar nodes, congestive heart failure with perivascular edema, and partial opacification of pulmonary veins can all simulate filling defects and are possible sources of false-positive interpretations.

Because of these problems, spiral CT may fail to detect small emboli. Even with an optimal technique and image reconstructions, the accuracy of spiral CT for the detection of pulmonary emboli beyond the segmental level is less than that of conventional pulmonary angiography. Isolated small emboli are probably rare, however. In the PIOPED trials, a solitary pulmonary embolus distal to a segmental level occurred in only 14 of 251 patients.

Recent technologic advances have also allowed the pulmonary vasculature to be visualized with magnetic resonance imaging (MRI). This is achieved using faster pulse sequences with shorter echo times, body coils, and by timing image acquisition to specific phases in the cardiac and respiratory cycle (cardiac and respiratory gating). The advantage of MRI in the evaluation of thromboembolic disease is twofold. First, it can provide three-dimensional images of the pulmonary vascular bed in multiple projections without requiring the administra-